CLASSIFICATION OF CRITICAL AGING SEGMENTS OF POWER TRANSMISSION LINES

NUR AZLIATUN HISAN BT MOHAMED ARIFFIN

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ABSTRACT

An Analytic Hierarchy Process (AHP) approach been used for analysis, comparison and classify the quality of several parameters that affect the conductor thermal ratings. The method is based on pairwise comparison between several factors that affect the alternatives in a hierarchical structure. The thermal ratings of power transmission lines is basically based on the maximum permissible temperature of the conductors. Conductor can lose their tensile strength due to thermal load or annealing. This paper analysis thermal aging using known characteristics of transmission conductor, load information and weather data. By analyzing the conductor temperatures, aging due to loss of conductor tensile strength is estimated at individual locations along the transmission corridor. The proposed methodology is illustrated using a case study analyzing a power transmission line in Kluang, Johor. This information is important for transmission network operating procedures, scheduling of line inspections, maintenance, or reconductoring.

ABSTRAK

"*Analytical Hierarchy Process (AHP)*" adalah satu kaedah yang digunakan untuk membuat analisa, perbandingan and mengklasifikasikan kualiti beberapa parameter yang mempengaruhi kadar terma konduktor. Kaedah ini berdasarkan perbandingan secara pasangan diantara beberapa factor yang mempengaruhi alternatif pada struktur hierarki. Kadar terma bagi talian penghantaran kuasa adalah secara dasarnya bergantung kepada kadar maksimum haba atau suhu yang dibenarkan bagi sesebuah konduktor. Kehilangan kadar regangan bagi sesebuah konduktor merujuk kepada beban terma dan "*annealing*". Tesis ini menganalisa mengenai "*thermal aging*" berdasarkan pengetahuan berkaitan cirri-ciri pada konduktor penghantaran , kadar beban dan juga data cuaca. Berdasarkan analisa suhu haba pada konduktor , "aging" yang merujuk kepada kehilangan kadar regangan dapat ditentukan bagi setiap lokasi individu disepanjang korodor penghantaran. Metodologi, ilustrasi dan seterusnya analisa bagi projek ini , lokasi talian penghantaran yang digunakan adalah di Kluang, Johore. Informasi atau hasil pengetahuan daripada projek ini adalah penting bagi langkah operasi bagi jaringan talian penghantaran ,panduan jadual pemeriksaan, penyelengaraan ataupun pengawalan.

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LIST OF SYMBOLS

Symbol	Description	SI units
qs	Heat gain rate from sun	W/m
Qs	Total solar and sky radiated heat flux rate	W/m2
Qse	Total solar and sky radiated heat flux rate elevation corrected	W/m2
R(Tc)	AC resistance of conductor at temperature	Tc Ω/m
Ta	Ambient air temperature	°C
Tc	Conductor temperature	°C
Tfilm	(Tc + Ta)/2	°C
Vw	Speed of air stream at conductor	m/s
Zc	Azimuth of sun degrees	
α	Solar absorptivity (0.23 to 0.91)	—
δ	Solar declination (0 to 90) degrees	—
ε	Emissivity (0.23 to 0.91)	—
φ	Angle between wind and axis of conductor degrees	
β	Angle between wind and perpendicular to conductor axis degrees	
ρf	Density of air	kg/m3
θ	Effective angle of incidence of the sun's rays degrees	
μf	Dynamic viscosity of air	Pa-s
ω	Hours from local sun noon times 15 degrees	
χ	Solar azimuth variable	—

CHAPTER 1

INTRODUCTION

Electric power transmission or "high voltage electric transmission" is the bulk transfer of electrical energy and a part of our life. It is start from generating power plants to substations. It is a very complex systems that always run near their operational limits. In Malaysia more than 420 transmission substations are linked together by approximately 11,000 km of transmission lines operating at 132, 275 and 500kV. The amount of power that an overhead transmission line can transfer is affected by the conductor's ability to radiate thermal energy.

What is conductor? Conductor is a medium that used to carry the electrical current flow from one to another destination. It is one of the important element for overhead transmission lines . Cost for conductor gives 20% from overall construction for transmission lines itself. Conductors can lose their tensile strength due to the adverse effects of conductor aging caused by annealing.

Therefore, it is important to keep track of conductor temperatures over time in order to identify segments of power transmission network that may require more close attention, repairs or reinforcements as shown in Figure 1.1. If no action we take, it would be extremely expensive and most likely impossible to protect a power system against any disturbances.

Therefore this project describes and illustrates one methodology for classification and identification of critical aging segments for a single location of a sample transmission lines. This project will use load information and weather condition derived from historical weather reanalysis and interpolate to location of power transmission lines. Conductor thermal load is first will determine using IEEE 738 Standard [8] and then use to estimate loss of tensile strength for each of the conductor.

This paper is organized in five chapters. Chapters 2 provides background information on transmission lines overview, analytical hierarchy process (AHP), conductor thermal state, conductor aging behavior, emissivity of conductor surface and etc. Methodology is introduced in chapter 3. A case study involving a sample transmission line is presented and analyze in chapter 4. The last chapter provides major conclusions and indicates directions of future work.

Figure 1.1 : Maintenance at Transmission Lines

1.1 Problem Statements

Malaysia nowadays is a developed country. Many building, factory and house been developed. Because of this demand for power are so high and it make electrical power industry under increased pressure to cope with it. Because of this reason, it is so important to identify segments of power transmission lines that may require more close attention, repairs or reinforcement rather than require new line construction.

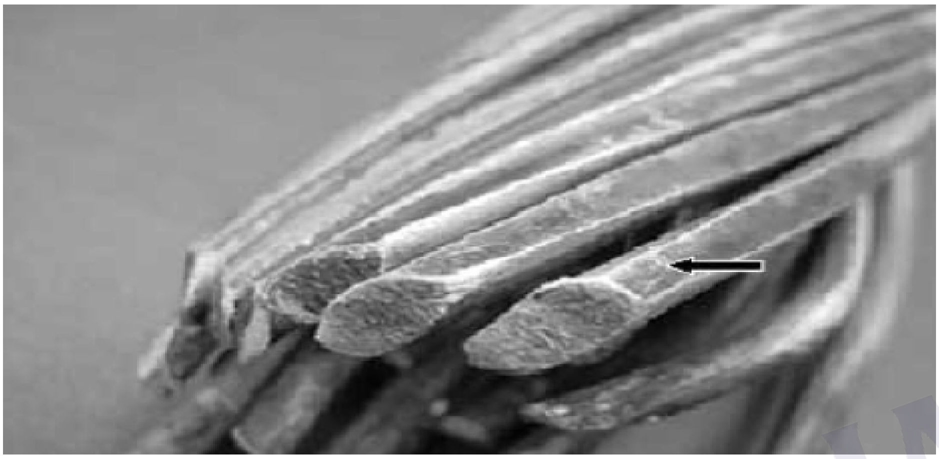

Figure 1.2 : Detail showing superficial damage (see arrow) of the external aluminum strands

1.2 Project Objectives

1) To determine which parameters effect more in the amount of thermal load current.
2) To evaluate aging of an overhead conductor and determine how much aging had occurred over the period of interest.
3) To identify critical aging segments and hotspot localization depends on information about the power transmission line and its environment.

1.3 Project Scopes

1) Analytical Hierarchy Approach (AHP) is chosen for determine parameters prioritizing give effect for conductor thermal load amount.
2) A sample power transmission lines has been selected from Kluang (KLUG) - Kluang Industry (KLID), Johor. The conductor used is 1x300mm² ACSR (Aluminum Clad Steel Reinforce) conductor “Batang” with the aluminum strand diameter of 24.16mm and the nominal current is 660 A.

CHAPTER 2

LITERATURE REVIEW

In order to achieved the objectives it is necessary to know the basic information of all the parameters contributed in this project area. This chapter will provides the background information transmission lines, analytical hierarchy process (AHP), conductor thermal state calculation, conductor aging behaviour, emissivity of conductor surface, characteristics of conductor ACSR in high of temperature and characteristics of ACSR.

2.1 Transmission Lines

The main parts in electrical flow of high voltage shows in Figure 2.1, while Figure 2.2 is the illustration of power system components. Transmission lines are used to transmit large amounts of power across power systems. Important characteristics are impedance, operating voltage, and ampacity. Transmission line steady-state loading is a function of many variables, including sending end voltage, receiving end voltage, available generation, system load, and current distribution among parallel current paths. Transient loading is a function of the fault or abnormality that initiated the transient in addition to the preceding factors. Both normal and emergency power-transfer capability must be considered when setting transmission-line protective devices.

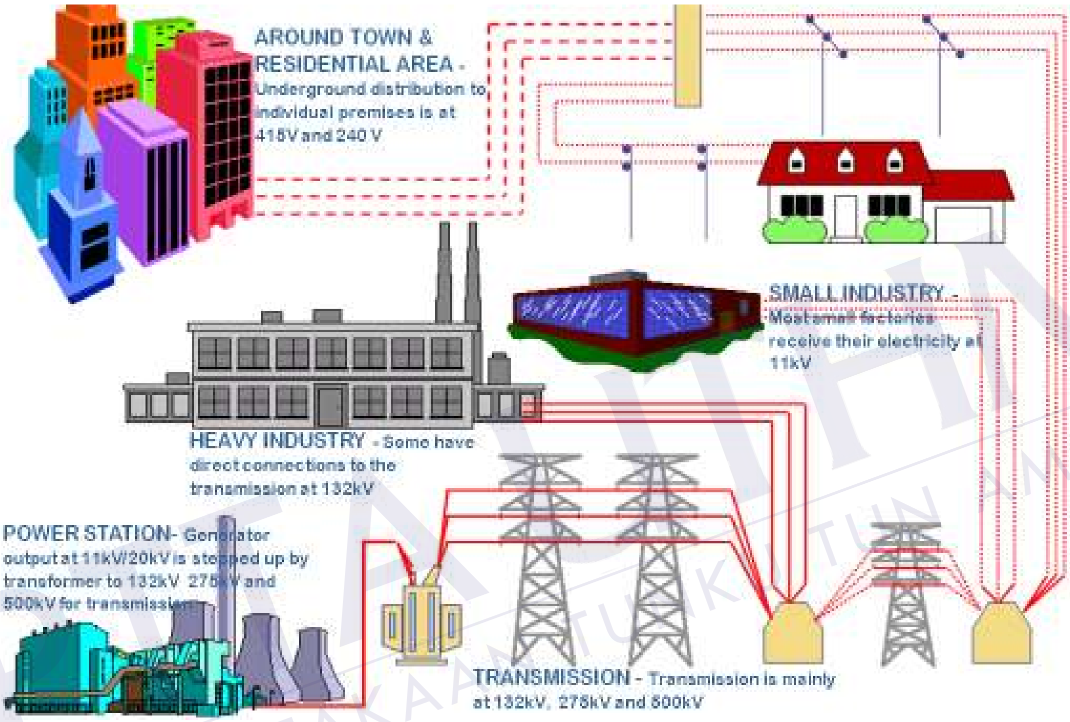

Figure 2.2: Power system components

2.2 Analytical Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) is used in this study to evaluate several parameters that was give priority effect in conductor thermal load. The parameters was defined which are conductor temperature, ambient temperature, wind velocity, elevation, solar radiation and emissivity. After done this process and getting the result only the most essential criteria will be selected and focus to study. The result will show that the used approach made the running process selection more overall ,more scientific, and more precise. This method also was chosen because according to some readings and study it is found that the application of this method is widely used. It can be applied to power system, telecommunication, electrical and electronic, business, education and many more.

Table 2.1 The fundamental scale of absolute numbers

<table>
<tr><th>Intensity of Importance</th><th>Definition</th><th>Explanation</th></tr>
<tr><td>1</td><td>Equal Importance</td><td rowspan="2">Two activities contribute equally to the objective</td></tr>
<tr><td>2</td><td>Weak or slight</td></tr>
<tr><td>3</td><td>Moderate importance</td><td rowspan="2">Experience and judgment slightly favour one activity over another</td></tr>
<tr><td>4</td><td>Moderate plus</td></tr>
<tr><td>5</td><td>Strong importance</td><td rowspan="2">Experience and judgment strongly favour one activity over another</td></tr>
<tr><td>6</td><td>Strong plus</td></tr>
<tr><td>7</td><td>Very strong or demonstrated importance</td><td rowspan="2">An activity is favoured very strongly over another its dominance demonstrated in practice</td></tr>
<tr><td>8</td><td>Very, very strong</td></tr>
<tr><td>9</td><td>Extreme importance</td><td>The evidence favouring one activity over another is of the highest possible order of affirmation</td></tr>
</table>

Here it can conclude that there are two important issues in group decision making. It is very important to organized way to make decisions and collect information relevant to them when a group must decide by laying out all the important factors and negotiating their understanding, beliefs and values. The AHP has been used in various settings to make decision for example :

A Telecommunications Quality Study Using the Analytic Hierarchy Process written by Christos Douligeris, Member, IEEE, and Ian J. Pereira[2] in their journal stated how AHP has been used as analysis and comparison of the quality of several telecommunications companies and for evaluation of alternate technologies in telecommunications. This is also namely as dilemma faced by a customer in choosing a telecommunications company that best satisfies the customer needs.

Here they utilize the AHP to scientifically choose a telecommunication company and particular services that best satisfy his needs for quality and services provided. Through AHP, it will determines the relative importance of each of these factors and their effect on the quality of services by performing pairwise comparisons between them. This enables the prioritization of their importance in a systematic way that efficiently relates the importance that each company assigns to these factors in its quality improvement program. The decision-making process in this case is greatly simplified by solving the problem in a straightforward numerical manner. After going through this paper noticed that the AHP method used for dealing with problems which involve the consideration for multiple criteria simultaneously. It is unique in its ability to deal with intangible attributions and to monitor the consistency with which a decision maker makes his decision.

Application of Analytic Hierarchy Process in Power Lines Maintenance Zhiling Lin, Liqun Gao, Dapeng Zhang, Ping Ren and Yang Li,College of Information Science and Engineering, Northeast University [3]. In this paper Analytic hierarchy process (AHP) created by Professor T.L. Saaty in Pittsburgh from University in United States was chosen as an effective method that can solve a multiple criteria and multiple objective decision-making problems was introduced to the power lines maintenance problem in order to gain a scientific and objective maintenance scheduling. Figure 2.2 below shows about an AHP structural model of power lines maintenance :

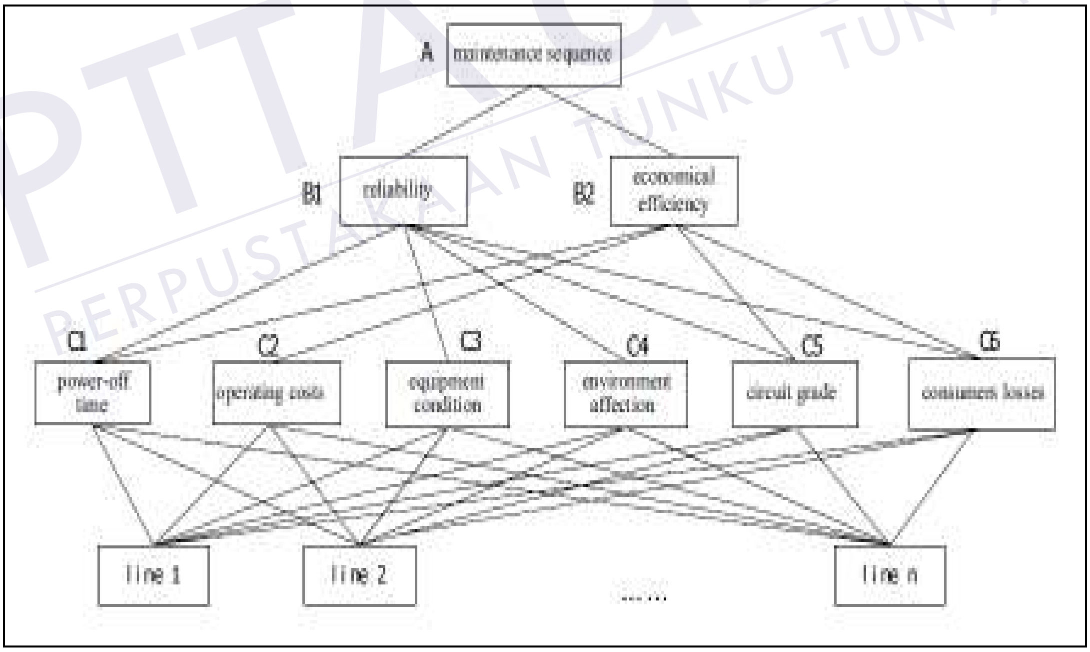

Figure 2.3: AHP Structural Model of Power Lines Maintenance (Zhiling Lin, Liqun Gao, Dapeng Zhang, Ping Ren and Yang Li,2006)

Factors on affecting the power lines maintenance, and their relations are very complex. That an AHP method is introduced to the power lines maintenance is a beneficial search to build a scientific and objective evaluation mechanism in the complex system.

2.3 Calculation of conductor thermal load

Procedure outlined in IEEE Standard 738 [8] is present a method of calculating the current-temperature relationship of bare overhead conductors. Conductor surface temperatures are a function of the following :

2.4 Conductor aging behavior

Conductor aging is an inevitable process affecting all components of power transmission systems. Annealing due to high temperatures, is one of the main reasons for permanent damage of aluminum strands in ACSR conductors. Furthermore it is a crucial factor for assessing loss of strength of power transmission lines due to. Therefore, high operating temperatures are the primary concern for this type of aging.

From this investigation, knowing that for a given temperature and time exposure, small diameter wires will lose a greater percentage of strength than will large diameter wire. The strength remaining after emergency operation a elevated temperatures of aluminum transmission line conductors can be calculated using the models (SAC,ACSR,AAAC and ACAR) developed in this paper. Aluminum annealing begins at 100°C, and it becomes drastic above 200°C and the percent of loss of tensile strength of an aluminum conductor strand depends on several parameters :

$$L_{AL} = 100 - k \cdot t^{\frac{1.6}{0.63 \cdot d}\left(0.001 \cdot T_c - 0.095\right)} \qquad (2.2)$$

Where, L_{AL} is the percentage of loss of strength, *d* is the strand diameter [mm], t is the exposure time [hrs], T_c is the conductor temperature [°C], and $k = \left(-0.24 \cdot T_c + 135\right)$ This empirical equation can be used to create a family of annealing curves for discrete values of temperature. Loss of strength determined this way is valid only for a single aluminum strand.

The loss of tensile strength is caused by recrystallization process in aluminum strands. During this process, new strain-free grains of metal replace the old deformed grains which occur during the nucleation process. As a result, the hardness of the metal gained by the cold work is gradually consumed by the movement of the large scale grain boundaries.

2.5 Emissivity of conductor surface

The emissivity of the surface of an overhead, stranded, transmission conductor is one of the factor governs the current carrying capacity. C.S Taylor, nonmember AIEE and H.E.House, member AIEE [16] study using data tending to confirm the values of emissivity obtained and present in the form of actual temperature rises of several sizes of stranded conductor under controlled conditions in 1956. Through their discussion about the relation of emissivity study to transmission practice , the values obtained by method described in this paper indicate emissivity values for new conductor vary between 20-25% of emissivity factor and conductor blackened by service may as high as 91% .

2.6 Characteristics of ACSR conductors at high temperature

The top sketch shows the conductor at room temperature where the unstressed length of the aluminium and steel members are equal. The second sketch shows the free thermal expansion of unstressed conductor where the two component have different lengths. The third sketch shows the condition where the two members are forced to occupy the same length resulting in a greater elongation of the steel core than in the case of the free expansion.

The bottom sketch illustrates the bird caged strands with a constant compressive stress S_b on the aluminium above the bird caging temperature, sag temperature, thermal elongation and stress-strain tests have shown that the compressive stress a limiting value at the bird caging temperature.

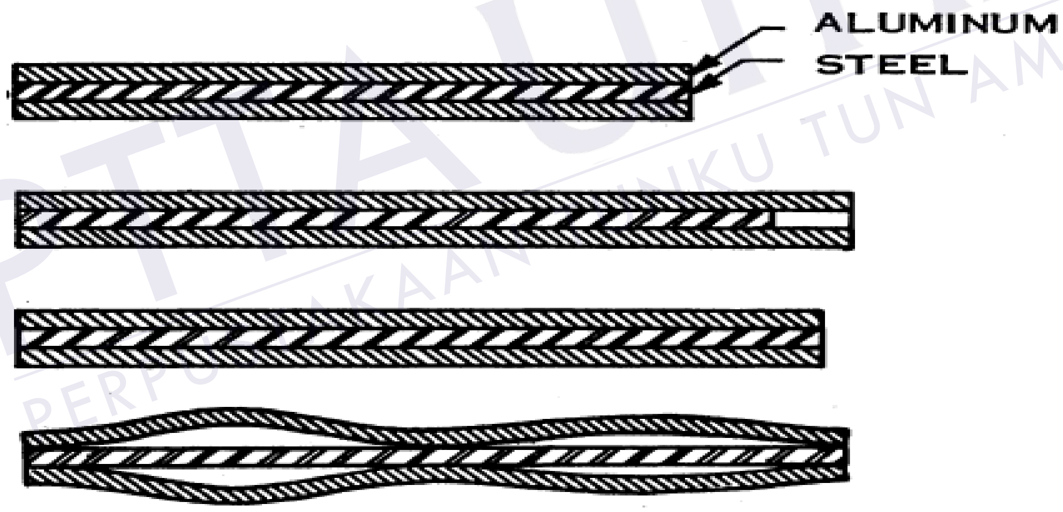

Figure 2.5 : A Simple Thermal Model Of ACSR Conductors

Some organic materials are known to be more affected by temperature than metals. When evaluating the temperature effects, it is important to consider both steady state and short term temperature swings. Changes are accentuated with the application of mechanical loads such as tension and vibration, both forms of loading conductors experience routinely in service. Figure 2.5 below shows the conductor damage effect by corona on conductor surfaces especially when wet or contaminated is normal.

Figure 2.6 : Conductor damage due to vandalism resulting in broken strands and exposure of core.

2.7 Aluminium Conductor Steel Reinforced (ACSR)

2.7.1 Characteristics of ACSR

Aluminum strand outer layer/layers are formed with centre core of single/stranded galvanized steel wires as illustrate in Figure 2.6. ACSR can be suitably designed for increased mechanical strength needs by increasing number of steel wires. It can also suitably designed for average mechanical needs by using higher aluminum and lower steel contents.

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